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Abstract

On the south shore of the western Mediterranean Basin, mountain forest ecosystems are degraded, mainly due to their overexploitation. Topographic, edaphic and climatic conditions create stressful growing conditions and sensitive ecosystems. Nonetheless, in these ecosystems, forests remain an important resource for the subsistence of local populations. Historically the vulnerability of this resource has prompted mankind to establish traditional control forms of forest and pastoral areas. These common resource management systems are still functioning in the Moroccan High Atlas Mountains under the name of *agdal* which refers to the territory, the resources and access rules laid down by the local population in order to manage the territory.

The estimation of land cover changes was a suitable method to evaluate the effectiveness of these community-based systems for forest conservation. In this paper we highlight the impact of this traditional management on woodland dynamics in a mountainous area (Aït Bouguemez Valley) through the use of remote sensing approaches, associated with forest structure characterisation and the analysis of social mechanisms. A diachronic analysis based on the comparison of aerial photographs (dated 1964) with a recent Spot 5 satellite image (from 2002, 2.5 meters resolution) was performed. Estimation of changes in canopy cover percentage was achieved using a graphic chart as a base for the photo-interpretation, and a subsequent validation by field sampling. A map of canopy cover changes between 1964 and 2002 was produced. Ecological measurements of trees were also achieved on field plots.

The results indicate that in the past 38 years, forest ecosystems have been affected by a relative decrease of 20.7% of the total forest area, and 8.7% for the mean canopy cover percentage. However, strong disparities in forest dynamics arose according to the *agdal* or non-*agdal* status of the forest. Significant progression in canopy cover is noted in controlled *agdal* areas but large degradation has occurred outside. Regarding the stand ecological conditions, we observed significant differences in the stand structure, according to the management mode. We suggest through this study increased recognition of customary forest regulations, which may be adapted and extrapolated to other communities. However, from an ecological point of view, the *agdal* system alone is not sufficient to reach a viable management mode in the long term.

Keys Words: Moroccan High Atlas – Forest - *Agdal* – Remote sensing – Canopy cover - Vegetation structure – Traditional management

1 Introduction

In various marginal areas all over the world, exploitation of natural resources has long been controlled by traditional community-based rules of appropriation and extraction (Masri, 1991; Colchester, 1994; Genin et al., 1995; Berkes, 1999; Uprety, 2008). Niamir (1990) achieved an extensive inventory of the management rules encountered in African sylvo-pastoral resources. Considered for a long time as a relic of past, these practices — showing a good knowledge of ecosystems functioning and a good adaptability to changes — are nowadays subject of renewed interest especially due to the generalization of sustainable development rhetoric. One major debate is to know how to combine these traditional systems with modern state policies (Folke, 2004; Armitage, 2005).

In the Atlas Mountains a similar system is found under the name of *agdal* (Berque, 1978). *Agdal* is a Berber generic term designating areas where access rights and uses of natural resources are governed by a local institution – usually the village, inter-village or intertribal assembly – which fixes rules concerning boundaries, periods and modalities of natural resource exploitation (Artz, 1986; Auclair, 1996; Ilahiane, 1999; Venema, 2002; Auclair and Alifriqui, 2005). Although a*gdals* exist all over Morocco in various environments, our concerns will focus here on forest *agdals* which are less widespread and have been studied less than pastoral *agdals*. The valorisation of this local knowledge is also nurtured in Morocco by the widely accepted evidence of the general failure of modern institutions to manage the common sylvo-pastoral resources (Auclair, 2005). Many conservation programs in the world realized the necessity to have recourse for forest co-management in order to involve different actors: local communities, state-based authorities and nongovernmental organizations (Berkes et al., 2000; Plummer and FitzGibbon, 2004; Gautam et al., 2004; Michon et al., 2005).

However impacts of this type of management on forest dynamics and health are poorly documented and need to be objectively assessed. This aspect is critical, particularly since various authors argue that Moroccan sylvo-pastoral ecosystems experience a significant degradation of vegetation cover (Gauquelin et al., 2000; Lamb et al., 1991). This trend is due to the severity of topo-edaphic and climatic conditions, and to the anthropogenic pressure exerted on these areas (MCEF, 1999; Montès et al., 2000; Nygard et al., 2004). This pressure on forests can be interpreted as a consequence of four main factors: (1) the livelihood of rural peoples still relies quite exclusively on the self-sustaining exploitation of local natural resources for firewood, foliage fodder and timber wood; (2) a marked population growth in the last decades ─ especially since 1960; (3) a bioclimatic context limiting forest productivity (summer droughts and cold winters) strengthened by the recent climatic changes ─ Over the last fifty years the mean temperature in Morocco increased by 1°C (RDH50, 2006); (4) finally, in a broader historical context, a past colonial environmental policy that has led to a dispossession and a lack of responsibility of the indigenous to their territories (Davis, 2005).

The assessment of changes in forest canopy cover by using remote-sensing data is an objective method to evaluate the impact of human management (Taillefumier and Piégay, 2003, Wimberly and Ohmann, 2004, Dalle et al., 2006). The inventories and analyses of the social processes affecting forest use, and the interactions between the different users and decision-makers, however, remain necessary to interpret the changes revealed by remote sensing (Berkes, 1999; Olsson et al., 2000; Mascia et al., 2003; Semwal et al., 2004).

The general aim of this study is to assess the impact of *agdal* management on the dynamics of the woodlands in the Aït Bouguemez Valley, since it is one of the rare zones in the High Atlas where the legitimacy and the influence of local institutions (e.g. *agdal*) have less been curtailed by the extension of government bureaucracy. More specifically, we want first to assess the ability of remote sensing for forest canopy mapping in a context of mountainous area and open canopy cover. Secondly, beyond the widespread narratives of forest decline, we intend to quantify, in a spatialized manner, the actual past changes of forests, using also ground data for validation. Finally, the third objective is to get insights into the *agdal* actual ecological efficiency and its ability to ensure the sustainability of forest management.

2 Description of the study area

The Aït Bouguemez Valley is located in the middle of the Central High Atlas Mountains (Morocco) in the Azilal province. The study area is the upper part of this valley, covering an area of 13000 ha, with a mean elevation of 2000 m.a.s.l. (Fig. 1). It includes two valleys oriented East-West sheltering thirty villages: the *Ait Hkem* Valley in the North and *Ait Rbat* Valley in the South. These two valleys are delimited in the North and in the South by high mountainous ranges reaching 3700 m.a.s.l. (*Azourki, Waougoulzat*).

This valley occupies a wide syncline with a marl-chalky flat-bottom from the Superior Lias. Its geomorphology includes carbonate-bearing layers (calcareous and dolomite) and layers of marls organised in powerful syncline and anticline folds. Its flat bottom was formed during the quaternary era by alluvial deposits resulting from the closing of the valley by a landslide which created a lake, which later filled with sediments and deep deposits of fertile soil (Couvreur, 1968; Lecestre-Rollier, 1992).

This valley has a Mediterranean highland-type climate, with a semi-arid variant in the bottom of the valley and sub-humid on the most watered mountain sides (Couvreur 1968). The average monthly temperatures range between 5 and 20°C. The annual rainfall varies between 350 and 750 mm, and precipitations are irregularly distributed in time and space, but they are more abundant during autumn and spring.

The bottom of the valley includes annual crops (cereals, potatoes, market gardening) as well as tree crops (apple, walnut) irrigated by traditional channels (*seguias*) diverting water from the rivers. The village boundary is organised perpendicularly to the mountainous axis. One can find, from the bottom to the top, the irrigated crops, the villages (*douars*), and some plots of dry cultivation (*bour*). The mid and high parts of the slopes are occupied by communal woody territories supplying firewood, leaf fodder and supporting grazing flocks. The lower parts of the wooded area close to the villages are often managed as *agdal,* while the high forest areas (outside *agdal*) are subjected to uninhibited forest utilization. The asylvatic areas in high altitudes constitute collective rangelands for ovine and caprine flocks. Some parts of these pastoral areas are also managed in *agdal* (Genin et al., 2009).

Forests and shrublands cover the north and south sides up to 2400-2700 m.a.s.l. and show contrasted densities and degradation levels. The vegetation is arranged in levels according to the altitudinal gradient: with phoenician (or red) juniper (*Juniperus phoenicea*) more abundant at the low and mid elevations as well as on the sunny south-facing sides. At medium altitude, we find holm oak (*Quercus ilex* L.) and prickly juniper (*Juniperus oxycedrus* L.). Finally, at higher altitudes appears the Spanish juniper (*Juniperus thurifera* L.) in open stands, representing the upper tree-line.

3 Forest management, the opposition between *agdals* and government policy

Agdal always consists of a temporary suspension of resource gathering aimed at preserving resources and creating stocks for critical periods. The subject of control mainly concerns pastoral resources in the asylvatic upper parts of mountains (Bourbouze, 1982; Gilles et al., 1992; Ilahiane, 1999), but other resources such as forest products, fruits, and crops may be concerned. Sacred areas (sanctuaries) are also affected by this type of collective land management. A village's forest territory in the Central High Atlas is usually divided in two parts: a weakly regulated area where the major extractions of firewood and fodder occur, and one or two *agdal* areas (between 20 and 200 ha), representing between 10 and 40% of the total available forest territory. The management rules of *agdal* usually refer to standing wood and foliage fodder collection, while grazing is authorized year-round. During periods of cutting exclusion (usually from March to November), people obtain their supplies from areas outside of the forest *agdal*. These areas are then submitted to higher harvest pressure. Some villages have framed resource use for extra-*agdal* territories also. Regarding tree foliage collection, which constitutes up to 20% of the annual diet of non-transhumant small livestock (Genin et al., 2009), four types of rules can be prescribed, which vary depending on villages:

- Cutting Period: In the villages we studied it covers the periods when snow covers the area, possibly from December to April. Cutting can be authorized every day or only during specific days of the week.
- Quantities Harvested: Different configurations occur: no quotas or quotas based on the size of the family flock or fixed equal quotas for each family.
- Division of *agdal* in sector in order to allow collection rotation.
- Specifying Tree Species for Cutting: In some villages only holm oak is authorized for foliage cutting while cutting junipers is strictly forbidden. The motive adduced by peasants is that holm oak is more able to produce leaf regrowth.

This body of rules can fluctuate depending on the size of forest *agdals*, occurrence of extreme climatic events, perceptions concerning the state of natural resources and battles of wills within village assemblies (Lecestre-Rollier, 1986). Other products from forest *adgals*, such as firewood or timber for roof construction, are submitted to prior authorization by the village's assembly who determine in a timely manner how they are to be used. Custodians of the *agdals* are sometimes designated locally and contraveners are fined or handed over to local authorities.

Overlapping with the *agdal* management are the state forestry policies in Morocco, which were conceived during the French protectorate period (1912 – 1956). They were essentially based on "declensionist" narratives of the decline of a previously fertile landscape by centuries of deforestation and overgrazing by Arab nomads and later by the Berber indigenous (Davis, 2005). However, recent paleoecological studies have questioned the rates of deforestation in Africa (Fairhead and Leach, 1996). The strategy adopted afterwards by the forest department to reconstitute the assumed degraded lands consisted of restricting access to "forest lands" — including all forested areas and rangelands outside irrigated farmlands. These areas came under the review of the forestry department; in these spaces cutting green wood is forbidden, while the right to gathering deadwood on the ground and grazing are granted to the local population (*Dahir* from 1917: Moroccan Royal Decree that constitutes the basis of the Moroccan forest code). However, the Moroccan Forest Code was not enforced in the Aït Bouguemez Valley until the implementation of a Forest Guard in 1985. Despite his presence, federal law enforcement measures were ineffective in practical terms, in view of the dominance and power of local law (Lecestre-Rollier, 1992; Aubert et al., 2009).

The environmental and socio-economic services delivered by *agdals* are closely linked to the overall functioning of the local agro-sylvo-pastoral system and the socio-territorial organization of Berber society (Bourbouze, 1999). Thus, exogenous state regulation is poorly compatible with local lifestyles (Aubert, 2009). Despite the progressive introduction of gas for cooking in the last few years, wood harvesting is still necessary for heating and to provide leaf fodder, especially for the poorest families whose purchase capacities are very limited. Over time, a status quo has set in between the traditional rules and the Moroccan forest law.

4 Materials and methods

The analysis of the actual forest structure and its comparison with canopy cover obtained from remote sensing are both important for assessing the accuracy of changes which have occurred (Hudak and Wessman, 1998; Ingram and Dawson, 2006), and also for better understanding different factors leading to these changes. Many authors have successfully mapped forest changes from satellite images (Hall et al., 1991, Cayuela et al., 2006, Dalle et al., 2006), as long as variations in species and densities were significant enough to influence the spectral signatures. However, for an accurate assessment of a canopy cover percentage, especially when variations are subtle, aerial photographs are more suitable (Hudak and Wessman, 1998, Carmel and Kadmon, 1998, Kadmon and Harari-Kremer, 1999, Tuominen and Pekkarinen, 2005). In order to observe the changes that occurred during the last forty years on canopy cover, we compared aerial photographs from 1964 with a very high resolution Spot 5 panchromatic image (2.5 meters resolution) from 2002. To go further and reveal the influence of the management practices on the characteristics of vegetation (Vermeulen, 1996), field measurements describing forest structure were conducted inside and outside *agdal*. We put emphasis on holm oak because of its extensive use as forage and firewood, and on juniper as endangered species (Gauquelin et al., 2000). This synchronic approach enabled us to establish the compatibility between the changes observed from remote sensing and the current state of the forest structure, which is useful for refining the analysis of change processes (Ingram and Dawson, 2006). Enquiries on land-use regulations, local perceptions, and interferences between the different actors who were part of this study provided more arguments to better interpret and understand the changes that occurred in forest stands (Dalle et al., 2006).

4.1 Remote sensing data processing

The data used for this study include:

- A SPOT 5 panchromatic satellite image dated 13 October 2002, at 2.5 m resolution.
- A set of aerial photographs dated August 1964 at 1:40000 scale. They were scanned at 300 dpi resolution resulting in an approximate ground resolution of 3.4 meters.
- A digital elevation model at about 80 m spatial resolution (SRTM mission, http://seamless.usgs.gov/).
- Topographic maps at 1:100000 scale (Zaouiat Ahansal sheet, issued from aerial photographs from 1964).

The aerial photographs and the SPOT image were orthorectified using image processing software (ENVI 4.2 © RSI), using the digital elevation model and the georeferenced topographic map.

In order to choose a suitable method to derive the canopy cover from aerial photographs, a review was made. Digital processing has often been used, either applying texture analysis (Hudak and Wessman, 1998, Tuominen and Pekkarinen, 2005), or simple thresholding techniques (Epp et al. 1983; Warren and Dunford. 1986; Spencer and Hall, 1988). Tree canopies generally appear dark on clear soil. It is thus possible to threshold the images to distinguish between soil and canopy, generating a binary image giving their areas. However, the heterogeneity of grey levels for the same objects in one document — especially due to variable ground illumination, variable soil brightness and photographic vignetting effect — made it impossible to apply a single threshold for a whole photo or image, and required complex radiometric corrections (Carmel and Kadmon, 1998, Tuominen and Pekkarinen, 2004). We chose instead to use visual photo interpretation to derive the canopy cover percentage from the orthorectified black and white documents, on which homogeneous polygonal units were delineated using a GIS software (Arcview © ESRI). During the same process, the extent of villages and irrigated areas was delineated.

The canopy cover percentage of these units was estimated visually based on a graphic chart figuring various cover percentages (Godron et al. 1983). Rousset (1999) also used this method and estimated a mean error of 10%, or 20% for a non specialist. Moreover, Defourny (1990) and Kadmon and Harari-Kremer (1999) showed that the visual estimates of canopy covers were equivalent to numerical thresholding. To reduce interpretation errors, the task was subsequently validated by a second photo interpreter. A limitation of this method lies in the confusion between the trees and their shadows, these two elements having the same grey level. The shadow is determined by three factors: the morphology of the trees (height – diameter ratio), the slope and aspect of the ground relatively to the sun (thus the time and date of acquisition of the data), and the observation angle of the sensor. As it is impossible to account for all these factors during interpretation, the visually estimated percentages we subsequently scaled based on ground measured percentages (Ko et al., 2009). Ground measurements of canopy cover percentage were achieved as explained in the following section, and they were compared with visual estimates of the 2002 image. A regression line was obtained and was applied to estimated percentages for both dates, assuming the correction was the same. The map of changes between both dates was obtained by overlaying the maps for each date and computing the differences in estimated canopy cover percentage.

4.2 Ground characterization of forest stands

The *agdals* were delineated by walking along the boundary with a GPS receiver with the help of the local natural resource managers. *Agdal* management practices were characterised in 2004-2005 during an earlier interdisciplinary survey using anthropological enquiries with stakeholders and local authorities (Auclair, 2005; Cordier and Genin, 2008).

The ground sampling was done for 85 plots (fig.3) with a stratified distribution covering the diversity of forest types and management, during the period from April to July 2007 (Cordier and Genin, 2008). The plots were squares of 20 or 40 meters per side, depending on the tree density ─ at least twelve trees per plot (Pardé and Bouchon, 1988), covering a total area of 3 ha. In order to compare the visually interpreted percentages with ground values, the plots were also spatially clustered in 27 sites homogeneous regarding canopy cover percentage, each of them including three plots, exceptionally two or four. The visual percentage cover for each site was linked with the average of the corresponding plots. The area sampled ranged over the entire canopy cover percentage values, and over various types of change (decrease, increase, stability).

In order to measure the canopy cover for each plot, the crown projection of each tree (Cp) was calculated with the mean of perpendicular diameters (D1, D2) and using the oval area equation: $Cp = 0.25 * \pi * D1 * D2$.

In order to assess the changes observed between the two dates, a description of the ecological conditions of individual trees and of the stand as a whole was achieved. The following parameters were recorded in each plot (Montès et al 2000, 2002; Cordier and Genin, 2008):

- Species and morphology of each tree: well-defined multi-stemmed or single-stemmed trees, and bushy stature (includes multi-stemmed and less than 1,80m height).

- Tree's height, and tree diameter at breast height from which the tree basal area was calculated

- As an indicator of pressure on forage resources, the net foliage volume was measured using the ellipsoid volume formula, on the basis of the two diameters and the height of the crown.

- The numbers of regenerations and stumps were also listed. Regenerations considered here are isolated young trees, resulting from natural seeding, layering or sprouting from root systems.

Specific variables were observed for holm oak stands, which represent the majority of the forest cover. They are the most prone to harvesting to ensure leaf fodder and combustible supply, and have a good capacity of regeneration due to their sprouting ability (Retana et al., 1992; Espelta et al., 2006). Thus, cuttings produce coppice stands that may get higher if they are not cut again. The inventories carried out for holm oak included: tree crown's transparency by estimating the holes in crown — taken into account for computing the net crown volume, the distribution of stem diameters and the coppice cover percentage.

To assess the differences between management and change classes, ANOVA (Analysis of Variance) was applied for each variable observed, and MANOVA (Multiple Analysis of Variance) was also used for global discrimination between classes. The analyses were achieved including all species. For the analysis of *agdal* management, holm oak and juniper species were also considered alone, taking into account only plots where they were present and only the data regarding each species. We considered that a difference was significant below a probability of 0.05.

5 Results

5.1 Accuracy assessment of canopy cover percentage estimates

There was a general agreement between the ground cover percentages and the visual estimates for the 27 sites plots available ($R^2 = 0.77$) (Fig.2). However, a bias appeared between the two variables since the visual estimations showed an overestimate of about 7.5% compared to the actual percentage. This bias is due to the shadows which were confused with the crowns on a black and white document. The linear relation is nevertheless well determined, and it was applied to all polygons on the map. The outlier with high cover percentage was kept as it is not an error, but a site including big trees on a very steep slope, producing a lot of shadow. However, removing this point would decrease the overestimation to 4.5%. This shows that the absolute canopy cover percentage may still be affected by errors, but they are not affecting the relative 1964-2002 difference we are focusing on. The relation was defined for 2002, but we assumed a similar overall effect of shadows for the 1964 photographs and applied the relation to this date also. After correction, the residual RMS between estimated and ground cover percentages was 6.2%.

5.2 Trends in land cover

Changes in land use between 1964 and 2002 are presented in table 1. The area of irrigated perimeters shows a slight extension, and the village areas have almost doubled in the last 38 years (Table 1). This is especially the case in the *Aït Hkem* Valley where the population is more numerous than in the *Rbat* Valley. The forested areas showed a strong reduction by 1192 ha, meaning a drop of 20.7% in 38 years. This overall trend mainly included deforestation (total removal of the trees), but also some local spots of forest regeneration (trees recovery on previously bare soils) encountered on 35 ha (0.6%), and some plantations extending on 7 ha. Large changes affect the canopy cover percentages, with areas of regression, increase or stability (Fig. 3 - 4).

The overall change in the canopy cover percentage between 1964 and 2002 was estimated by computing the average value for each date on the basis of the same area, i.e. the union of areas occupied by forest at either date (5784 ha). For each date, we computed the average of the percentage of all polygons weighted by their area. The result was a decrease of the average canopy cover percentage of -1.3% (from 15 to 13.7%), which means a relative variation of -8.7% in 38 years. However, the average canopy cover percentage computed for each date taking into account only the forested areas, raised from 15.1% to 17.4%.

5.3 Changes in canopy cover inside *agdals*

The *agdal* forest stands occupy an area of about 1667 ha, which represents 36% of the total forest stands. Some errors of delineation are however possible, especially as these entities are not immutable but may be modified throughout the years according to the resource evolution or to the villagers' needs. *Agdals* concentrate all the positive changes of canopy cover: progression in canopy cover percentage on 54,4% of the *agdal* areas against 5.4% of regression (fig.3). They show an increase of the canopy cover percentage of 3.1% in 38 years (from 15.8% to 18.9%), which represents a relative progression of about 19.6%, that is to say 0.5% per year.

The results of the management practices survey show that the canopy cover may increase for several reasons (table 2). In some cases, the locals themselves notice an overexploitation of the *agdal*, consequently they modify its boundaries (Genin et al 2009). The competition between neighbouring villages may also trigger the creation of *agdals* by legal claimants to better control any intrusions. The plantations established by the Forest Office have also contributed to the local increase of canopy cover percentages. These plantations have contributed to the regeneration of 23 hectares of *agdals* which were bare in 1964. In some cases, forest exploitation is shifting inside the *agdal* area according to a rotation system, driven by the village council and linked to the stands' state so that the harvesting is done in the most productive areas, allowing the most degraded ones to regenerate.

In spite of this dominant tendency, some *agdals* were subjected to degradation between the two dates. The main reason was pressure on resources in the villages with scarce forest areas. In some cases the claimants had to switch to gas for cooking in the last few years and to buy firewood and wood charcoal from a neighbouring valley. The difficult regeneration of Spanish Juniper (Gauquelin et al 2000) may also explain the decrease of tree cover.

Deforestation in *agdals* can also be the result of unresolved conflicts between villages. The map shows that 45 hectares are deforested within the *agdals* mainly due to this reason (Fig.3).

5.4 Changes in canopy cover outside of *agdals*

As opposed to the *agdal* areas, the extra-*agdal* areas are marked by regressive changes. From the 4066 ha of forest located outside *agdals*, 1187 ha were deforested (29%). On the basis of the union of forested areas of 1964 and 2002, 42.7% shows a decrease of the canopy cover percentage (Fig. 5) — which includes the above mentioned deforested areas. Moreover the average percentage of areas outside *agdal* areas decreased by 3.1% in 38 years — from 14.6% to 11.5% — which means a relative decrease of 21.5%. The survey showed that extra-*agdal* areas are often remote from the villages and are the subject of conflicts over their use (Table 2). They were formerly shared between several *tribes*, and are still today claimed by the neighbouring villages, which encourages excessive exploitation.

5.5 Analysis of the stand's characteristics according to canopy cover changes and management modes

The analysis of canopy cover change that has been done so far has shown that changes observed in the map were corroborated by the history and the practices linked to these territories. In order to validate and detail this analysis, the relation between these changes, stand characteristics and management modes, was studied quantitatively for the 85 field plots. The measurements concerned only natural woodlands. Plantations are described in this study only by their stem density.

The overall comparison of the three classes of canopy cover change based on all variables using MANOVA shows a highly significant difference between change classes ($P<0.0001$). The ANOVA for each individual variable is presented in table 3. The canopy cover percentage decrease significantly from progression zones (29%) to regression zones (11%). The net crown volume, which is an indicator of harvesting of leaf fodder and branches, also drops markedly from progression ($5602m^3.ha^{-1}$) to regression zones ($1767m^3.ha^{-1}$). Regenerations are more abundant in areas of stability and regression. These classes are indeed the most exploited and are likely to produce sprouts since the dominant species is the holm oak, which is known for its regrowth and coppicing ability. Tree density is also much higher in areas of stability because the regrowth capacity is balancing exploitation, which is not the case in regression areas. The number of stumps is significantly lower in areas of canopy cover progression, which are less exploited, but the maximum is not observed in regression areas, because stump extraction is often carried out in these areas.

A comparative analysis of the ecological characteristics of the stands according to the status of *agdal* or extra-*agdal* forest was achieved based on ground observations (Table 4 and 5). The MANOVA applied on all variables showed very significant difference between *agdal* and extra-*agdal* areas (P< 0.0001) (Table 4). The canopy cover percentage dropped significantly from *agdal* areas (27%) to extra-*agdal* ones (12%) (Fig.6). *Agdal* areas contain significantly more tree stems, higher tree basal area, higher crown volumes, and slightly higher trees. Although the significance is poor, the number of stumps and regenerations is higher outside of *agdal* areas because of wood exploitation, as explained previously. Almost all of the plantations are observed outside of *agdal* areas, which corroborates the fact that planting operations prioritize the most degraded areas. Most of these plantations are less than 10-years old, thus their positive effect on the canopy cover is not apparent on the remotely sensed data from 2002.

Considering the importance of holm oak in the study area, a specific analysis was done for these stands (Table 5). The MANOVA also show a significant difference between *agdal* and extra-*agdal* areas (P<0.0001) (Table 4). As a whole, the same tendencies as the global analysis are observed. *Agdal* areas show a significantly higher canopy cover percentage but fewer bushy trees. Crown transparency is higher outside of *agdals*, emphasizing the leaf fodder exploitation. There is a lower density of poles and medium stems outside *agdal* areas, but the number of big stems is the same. Conversely, more stumps are found outside *agdal* areas. This shows that exploitation may have first targeted areas with high wood potential, from which remain today large degraded trees, but with a significantly higher crown transparency and smaller crown volume. Indeed, the largest trees are not cut but only pruned because of the limited technical capabilities of the exploiters, usually women using axes and carrying wood on their backs.

A specific analysis was also conducted for junipers alone (Table 4), indicating no overall discrimination regarding the management type. However, regeneration densities ─ young trees and seedlings ─ are much lower than for holm oak, and regeneration is also higher in *agdal* areas (3.74 ha^{-1}) than outside of *agdal* areas (0.75 ha^{-1}) ($P< 0.05$). Crown volumes and tree heights are also significantly higher inside *agdals*.

6 Discussion

Our study highlights first the contribution and limits of remote sensing and GIS to carry out a diachronic analysis of forest dynamics by using the canopy cover percentage as an indicator of forest resources ─ since it is the main indicator accessible for panchromatic remote sensing data. Despite the methodological problems linked to the interpretation of photographs (crown's shadow, slope, subjectivity, etc.), ground observations ─ either regarding the canopy cover percentage or the stands' ecological description ─ corroborate the canopy cover estimates and their changes issued from visual interpretation. Furthermore, polygons of complete deforestation are easily validated as trees that are disappearing. This can be confirmed on the ground, as some stumps are often still visible. Therefore, the influence of these methodological limits remains relative and does not seem to significantly affect the mapping of canopy cover percentages.

6.1 Insights in landcover changes gained from remote sensing

Changes in land cover distribution were moderate and the valley still maintained the same landscape structure (Table 1). However, the change map shows that marked changes have occurred in forest areas since 1964. Despite the differential evolution of vegetation inside and outside *agdal* areas, the overall trend is a decrease in the wooded areas at an annual deforestation rate of 0.55% (disappearance of 20.7% of the forest areas since 1964, which means 31.5 ha each year). This figure may be compared with previous studies: the FAO (1995) statistics point out an annual deforestation of around 0.7% for Morocco which is consistent with Barbéro et al (1990) that suggests an annual rate of about 0.6% on the Moroccan scale. Indeed deforestation is very widespread outside *agdals* and especially the inter-village areas, in remote places away from the villages and also around the disputed boundaries of forest village territories. This decline of forest area is also linked with a drop in average canopy cover percentage (from 15 to 13.7%). However a closer analysis showed that this overall decrease of canopy cover was hiding an increase in density when considering only forested areas for each date (+2.3%). This densification effect is due to the fact that forest clear-cutting mainly affected areas of very low density, generally outside *agdals*, so that only dense forest patterns remain.

The overall forest decline hides significant contrasts regarding management modes. Canopy cover percentages increased in almost all *agdal* areas, and conversely it decreased almost everywhere outside *agdal* areas. This shows that this concept is still functioning, with the customary rules regulating access and uses. Moreover, we found during the survey that it is subject to adaptations through modifications of its boundaries or exploitation modes, to actually contribute to the resource preservation. We also observed the capacity of these stands to grow when protected, despite their age and the severity of the bio-physical conditions they are subjected to. Deforestation observed outside *agdal* is particularly intense in the *Aït Hkem* Valley, where strong tribal conflicts lead to severe tree pruning and even to land cultivations. In many cases, only the arbitrary power of forest administration may resolve these conflicts by replanting the stands claimed by the villagers (Fig. 6). Quite the opposite of the *Ait Hkem* Valley, degradation is almost nonexistent in the *Rbat* Valley. This contrast may be related to the fact that the first valley shows a much higher human pressure, showed by the larger increase of population (resp. +160% and +85%) and cultivated areas (resp. +10% and 0%), favoured by a softer topography. According to the last population census in 2006, the population in the studied part of the *Ait Hkem* Valley was 5182 inhabitants, compared to only 1610 in the *Aït Rbat* area, which represents a forest area per inhabitant of 0.67 and 2.3 hectares respectively. Moreover, the population of the *Aït Bouguemez* area has more than doubled since 1960 (Auclair 2005), especially in the *Aït Hkem* Valley where this demographic growth has correlated with the forest degradation.

Considering all forest areas, a positive gradient of degradation appears from the valley to the summits, which contradicts the classical areola model according to which the closer to the villages, the higher the degradation should be (Vermeulen, 1996; Ingram and Dawson, 2006). This fact is mostly due to the positioning of *agdals* near the villages. Despite the greater efforts required to exploit the forest far from the village, what prevails here is the necessity to keep a security stock of biomass close to the village for winter use. The *agdal* system leads therefore to a transfer of pressure from areas near the bottom of the valley towards remote areas closer to the top as well as towards other valleys (Aït Abbas, Aït Bou Oulli). Such a transfer from highly controlled areas to remote less controlled ones was also observed in the Himalayas (Jackson et al., 1998; Gautam et al., 2004). Our study emphasizes the major interest of spatialized analysis of local changes as opposed to global statistics, which in our case would have masked the *agdal* effect on forest changes. This point was also already mentioned in previous studies (Wimberly and Ohmann, 2004; Cayuela et al., 2006; Ingram and Dawson, 2006).

6.2 Insights gained from the ground observation of vegetation

The analysis of vegetation for the three types of change corroborated the mapping obtained from remote sensing. However, it appears that many areas mapped as “stable” also experienced a strong exploitation of vegetation which may have led to qualitative changes. More generally, the various canopy cover mapped using remote sensing may show very different morphology, which means that the changes in terms of area and percentage cover revealed by remote sensing analysis may neglect, at least locally, the qualitative changes of the vegetation. This fact underlines the limitation of remote sensing, which is efficient for mapping large areas, but fails when a detailed characterisation of vegetation is required, here for detailed change and management assessment (Wimberly and Ohmann, 2004; Cayuela et al., 2006; Ingram and Dawson, 2006).

Regarding the management modes, the analysis of vegetation characteristics shows that in *agdal* areas, stands are in better condition, with bigger trees showing larger basal area and larger crowns, showing evidence of little exploitation. The low wood exploitation is also unfavourable to the activation of vegetative regeneration for holm oak stands, which may in the long term endanger its sustainability. Conversely, outside of *agdals* the coppice resource dominates, trees are degraded and the abundance of holm oak coppices emphasizes the intensity of wood exploitation. When tree cover is maintained, it is often due to bushy stands, resulting from the degradation of previous tree clusters. The extensive wood and leaf fodder exploitation, combined with overgrazing, might even lead to the steppisation of these stands. These conclusions confirm a clear positive link between *agdal* management modes, the stands’ health condition and the stands' *de facto* dynamic.

A high regeneration was observed for areas outside *agdal* because these areas include mainly holm oaks, known for their sprouting ability. However, this regeneration is only linked to previously existing trees which have been cut, and rarely to seedlings. Regeneration is thus lower inside *agdals*, which are less exploited. As opposed to holm oak, regeneration of junipers is higher in *agdal* compared to outside *agdal*, and it is also on the whole much lower. This feature may be related to the poor sprouting ability of junipers, even if Bertaudière et al. (2001) found that crown mutilations affecting the apical bud could lead to multi-stemmed junipers with higher biomass. This low regeneration may also be linked with the known great difficulty of this species in germinating related to seed dormancy (Fromard and Gauquelin, 1993) and the elimination of seedlings by grazing. In our case the driving factor is grazing by small ruminants (sheep and goats), endangering the regeneration of these stands. The higher regeneration inside *agdal* can be linked with the higher proportion of this species in these areas, as grazing in the same in both areas. From this point of view, we can have doubts about the *agdal*'s capacity to assure the long-term durability of juniper stands. However some rare *agdals* have been tied to religious beliefs for many years and for this reason, have remained. In such spaces, which were not the focus of this study, various plant species were found as well as young tree shoots, and also well-developed undergrowth. Those spaces are likely to become an important reservoir of biodiversity in forest systems (Ilahiane, 1999; Becker and Ghimire, 2003; Bray et al., 2004).

6.3 Implications for forest management

The mean canopy cover percentage on the basis of the forest area in 1964 had a relative drop, - 8.7% in the last 38 years (from 15 to 13.7%), which means that two hectares of wood vegetation disappeared every year. This general trend encompasses two opposite evolutions, on one hand, an annual increase of canopy coverage by 1.4 ha in the *agdals*, and on the other hand, an annual decrease of 3.4 ha outside *agdal*. If we assume that the average conditions prevailing since 1964 remain almost the same, the crude temporal extrapolation of these two trends would show that there will not be any vegetation left outside the *agdals* in 2140. From this date, if the decreasing rate observed until this point in the extra-*agdal* spaces is applied, the vegetation will have totally disappeared by 2400. This extrapolation, although not realistic as a scenario, allows us to better realise the magnitude of the dynamics over these last 38 years. However, it may not absolutely represent the real future changes because of the difficulty of modelling the factors influencing this trend and the magnitude of human reaction capacity. On the other hand, the pressure exerted on forest depends on the socio-economic context and may change in the future, according to the changes that these societies are experiencing. Indeed, the rapid opening up of the valley due to tourism since the 1980's, the development of commercial agriculture and the national and international development initiatives — electrification in 2002, the introduction of the gas stove, the emergence of the cell phone in 2005, foreign aid offered by different NGOs — have widely contributed to accelerating the change of practices, as well as creating new production systems likely to partially reduce the pressure exerted on the forest. One example of these tendencies is the slight decline of pastoralism, which reduces the cutting of leaf fodder during the cold season, thanks to the increasing capacity of farmers to buy cereals instead (Aubert et al., 2009). However, in spite of the wide availability of gas, the use of wood is still essential to heat houses during the cold season and to operate the *hammams* (traditional baths).

The differential evolution of forests inside and outside the *agdal*, and the overall degradation of forest, emphasizes the failure of state-based policies to articulate with the traditional management of forest resources (Stevenson, 2004), especially in areas where customary management is absent. The same Moroccan forest code of 1917 implemented by the protectorate administration is still applicable. In other case studies, community management succeeded in preserving forest, with lower deforestation rates (Gautam et al., 2002; Bray et al., 2004; Dalle et al., 2006), or progression (Gautam et al., 2004). However it seems that each context is specific, and the question is not to know whether or not community management can lead to sustainable management of forest, as there is no general answer, but "what physical, economical and sociological conditions will make a community system succeed or not in this task ?" Indeed it is clear that communities have a strong interest in a good management of their resources (Kelbessa, 2005). However, as in any system, a sustainability crisis may appear due to the emergence of uncontrolled factors (e.g. population growth, climate, conflicts). To find a path towards a new equilibrium, all skills need to be mobilized, and the fusion of traditional and external (e.g. scientific) knowledge may bring the solution (Becker and Ghimire, 2003; Mascia et al., 2003; Kelbessa, 2005; Dalle et al., 2006).

In this case study, our findings indicate that the rationality in forest use still remains unworkable due to the absence of alternatives that would reconcile the ecological resilience, the mitigation of the current degradation trends, and the population's needs for livelihood. More specifically, the failure of forest management seems also to rely on the impossible equation between growing population needs and the physically limited production capacity of the natural environment (soils, climate) leaving no place to intensification, except with substantial inputs from outside the system. Such a saturation of traditional systems, triggered mainly by the population growth, is widely occurring in many places throughout the world (Niamir, 1990; Semwal et al., 2004). The solution relies on a deep transformation of the traditional system, typically changing from self-sufficiency to a higher level of connection with the external economy (people working in cities, multiplication of income sources). This explains why some forests close to urban areas may be in better condition than forests located in remote traditional areas (Gautam et al., 2004). A comparable environmental breakpoint was reached in the south of France in the 19th century, with a very strong degradation of mountains areas triggered by population growth, and was overcome during the 20th century with the transition from a self-sufficient agriculture to a wider opening to the national economy (Taillefumier and Piégay, 2003). It is worth mentioning that ironically in some marginal areas abandonment of farmland may even lead to a strong progression of forests which may in turn pose other problems (Olsson et al., 2000; Taillefumier and Piégay 2003).

In the Aït Bouguemez Valley, given the central role of forests in these agro-pastoral systems and the pressure exerted on it, no miracle solution exists which allows for forest conservation, as long as the populations do not get alternative resources out — or by transformation — of the traditional system. It would be desirable for the state-based institutions (forest office, universities…) to redefine, in agreement with the local population, enhanced models of forest management. Forest administrations should be asked to promote new approaches including decentralized and participatory management of forest resources. The implementation and generalization of the ministerial decree launched in 2002, regarding monetary compensation for the exclusion of grazing flocks, may be a first step to establish a more confident relationship with local populations and to allow forest regeneration. These proceedings could be instituted through a consultation with the village council and local associations. The role of local NGOs might be crucial to broker the negotiations between the traditional system and the state-based one.

7 Acknowledgments

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Table 1

Land use/cover dynamics during 1964-2002 period in hectares.

Land use/cover class	Area (ha) in 1964	Area (ha) in 2002	Gain (+) or loss (-) area during 1964-2002	Rate of change (%)
Forested areas	5755	4563	**-1192**	**-20.7**
Non-forested areas (Rangelands)	7157	8266	+1109	+15.5
Irrigated crops	504	530	+26	+5.2
Villages	40	97	+57	**+143.6**
Total	13456	13456		

Table 2

Main changes of percent canopy cover and suspected drivers of change obtained from a population survey.

Area	Dominant tree species	Vegetation change during 1964-2002 period	Cause of Change	Driver of change
Agdal Louta	*Q. ilex* + *J. phoenicea*+ *J. Thurifera*	Increase of canopy cover	Extention of the *agdal* boundaries (on East side, 2004)	Overexploitation by locals (Intensive cutting of wood and leaves)
Agdal Adazen	*J. phoenicea*		Creation of an *agdal* (1979)	To control the intrusions of neighbours
Agdal Ikhiss	*Q. ilex* + *J. Thurifera*		Creation of an *agdal* (1958) + plantations by the forest office (1986)	To control the intrusions of neighbours
Agdal Louta	*Q. ilex* + *J. phoenicea*+ *J. Thurifera*	Plantation of forest	Plantations of Arizona Cypress (*Cupressus arizonica*) by the forest office (~1995)	To prevent forest patterns from gathering (forest office decision or popular request)
Agdal Itghssi	*J. Thurifera*	Decrease of canopy cover	High pressure on a small forest area	Pole harvesting for building and difficult regeneration of Spanish juniper
All village-*Moucharikas**			High pressure	Lack of control due of the distance from villages
Agdal Manzart	*J. Thurifera* + *Q. ilex*	Deforestation (complete disappearance of forest)	Forest exploitation upstream from the *agdal*	Proximity of an old *moucharika** claimed by neighbours
Agdal Assamer	*J. Thurifera* + *Q. ilex*		Forest exploitation in the north-east of the *agdal*	
Intervillage-*moucharika** between the *agdals* Manzart and Tagana	Bare soil + Some land cultivation		Competition for wood clear cutting	Unresolved conflicts for territorial claims between neighbours
Intervillage-*moucharika** between the *agdals* Ikhiss and Assamer				

* Non *agdal* forest area, usually remote from villages, used for wood supply.

Table 3

Vegetation characteristics for the three canopy cover change classes between 1964 and 2002,and the related statistics (SS: sum of squares; df: degrees of freedom).

ANOVA	**Increase**	**Stability**	**Regression**	**SS model**	**SS residual**	**df model**	**df residual**	**F (Fisher)**	**P (5%)**
Number of plots	**24**	**46**	**15**						
Total canopy cover (%)	29.6	20.6	11.3	3169	13895	2	82	9.35	**0.0002**
Crown volume (m^3.ha^{-1})	5601.8	2770.9	1767.1	174544003	632984764	2	82	11.31	**< 0.0001**
Basal area (m^2.ha^{-1})	19.1	16.6	15.5	144	14932	2	82	0.40	0.6700
Trees height (m)	4.6	4.2	4.2	3	248	2	82	0.51	0.6000
Stem density (nb.ha^{-1})	246.8	558.3	122.9	2863895	14402811	2	82	8.15	**0.0006**
Plantation density (nb.ha^{-1})	12.5	49.9	197.7	340885	2906501	2	82	4.81	**0.0106**
Regenerations (nb.ha^{-1})	153.2	490.8	336.1	1815776	9934533	2	82	7.49	**0.0010**
Stumps (nb.ha^{-1})	22.5	103.9	75.3	104462	566257	2	82	7.56	**0.0010**
Indexes									
Crown volume / Basal area	293.1	166.9	114.3						
Nb of regenerations / Nb of stems	0.6	0.9	2.7						
Nb of stumps / Nb of stems	0.09	0.19	0.61						
MANOVA	**df1**	**df2**	**Lamba Wilk's**	**F (Rao)**	**P**				
	16	150	0.48	4.16	**< 0.0001**				

Table 4

Multiple analysis of variance of vegetation characteristics inside and outside *agdal* areas (df: degrees of freedom).

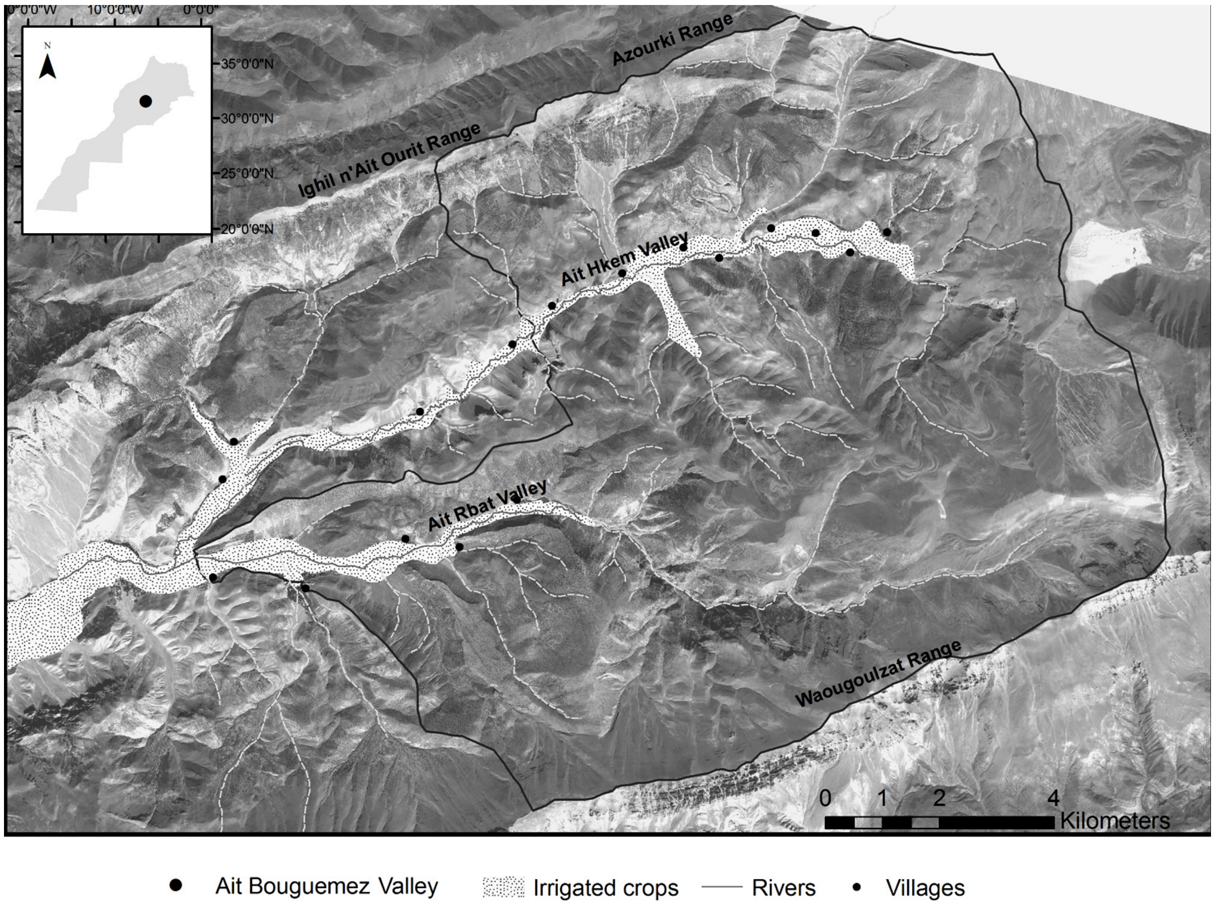
MANOVA	df1	df2	Lamba Wilk's	F (Rao's approx.)	P (5%)
All species	8	65	0.76	5.12	< 0.0001
Holm oak	10	55	0.53	4.96	< 0.0001
Junipers	7	55	0.85	1.37	0.24

Table 5

Analysis of variance of vegetation characteristics inside and outside *agdal* areas, and related statistics

ANOVA	***Agdal***	**Non *Agdal***	**SS model**	**SS residual**	**df model**	**df residual**	**F (Fisher)**	**P (5%)**
All species								
Number of plots	**52**	**33**						
Total canopy cover (%)	27.2	12.4	4445	12619	1	83	29.24	< 0.0001
Basal area (m^2.ha^{-1})	20.7	11.5	1703	13373	1	83	10.57	0.0016
Trees height (m)	4.6	3.8	12	239	1	83	4.28	0.0410
Crown volume (m^3.ha-1)	4658.1	1399.7	214337810	593190957	1	83	29.99	< 0.0001
Natural stem density (nb.ha^{-1})	493.2	236.5	1330321	15936385	1	83	6.93	0.0100
Plantation density (nb.ha^{-1})	9.4	153.7	420213	2827173	1	83	12.34	0.0007
Regenerations (nb.ha^{-1})	310.5	459.2	446581	11303728	1	83	3.28	0.0730
Stumps (nb.ha^{-1})	61.2	99.1	29074	641645	1	83	3.76	0.0560
Holm oak								
Number of plots	**39**	**27**						
Trees canopy cover (%)	19.6	8.8	1842	7254	1	64	16.25	0.0001
Bush cover (%)	3.0	13.2	1666	4444	1	64	23.99	< 0.0001
Crown volume (m^3.ha^{-1})	3238.9	847.9	91213730	393568425	1	64	14.83	0.0003
Basal area (m^2.ha^{-1})	16.7	10.1	696	7539	1	64	5.91	0.0180
Trees height (m)	4.4	4.0	2	293	1	64	0.53	0.4700
Stem density (nb.ha^{-1})	554.1	248.0	1494117	13137617	1	64	7.28	0.0090
Poles (7.5 - 17.5 cm)	397.1	147.7	992212	11801289	1	64	5.38	0.0230
Small stems (17.5 - 27.5 cm)	68.2	56.7	2110	284887	1	64	0.47	0.4900
Medium stems (27.5 - 47.5 cm)	75.9	32.6	29916	385879	1	64	4.96	0.0290
Large stems (47.5 - 67.5 cm)	11.8	10.2	41	31576	1	64	0.08	0.7800
Very large stems (> 67.5 cm)	1.1	0.8	1	1099	1	64	0.06	0.8100
Crown transparency (%)	11.5	23.9	2472	24165	1	64	6.55	0.0120
Regenerations (nb.ha^{-1})	319.8	545.5	812766	8348710	1	64	6.23	0.0150
Stumps (nb.ha^{-1})	58.3	106.7	37395	516994	1	64	4.63	0.0350
Cuttings, crowns and stems (nb.ha^{-1})	988.1	673.8	1576677	82091524	1	64	1.23	0.2700
Junipers								
Number of plots	**42**	**21**						
Total canopy cover (%)	15.53	8.11	771	11998	1	61	3.92	0.0522
Basal area (m^2.ha^{-1})	10.14	4.90	384	9313	1	61	2.52	0.1178
Trees height (m)	3.63	2.89	8	114	1	61	4.14	0.0463
Crown volume (m^3.ha^{-1})	2759.63	1109.48	38121526	453549085	1	61	5.13	0.0271
Natural stem density (nb.ha^{-1})	96.11	52.69	26396	602558	1	61	2.67	0.1072
Regenerations (nb.ha^{-1})	3.74	0.75	125	1676	1	61	4.55	0.0368
Stumps (nb.ha^{-1})	0.96	0.81	0	122	1	61	0.17	0.6800

Fig. 1



Azourki Range
Ighil n'Ait Ourit Range
Ait Hkem Valley
Ait Rbat Valley
Waougoulzat Range
10°0'0"W
35°0'0"N
30°0'0"N
25°0'0"N
20°0'0"N
N
0 1 2 4
Kilometers
Ait Bouguemez Valley
Irrigated crops
Rivers
Villages

Fig. 2

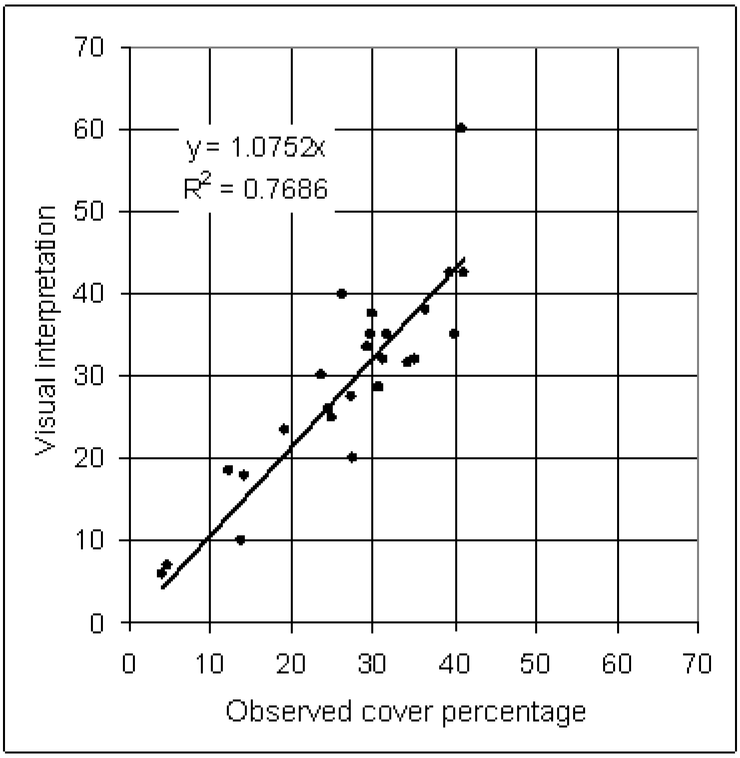

y = 1.0752x
R^2 = 0.7686
Visual interpretation
Observed cover percentage
0
10
20
30
40
50
60
70

Fig. 3

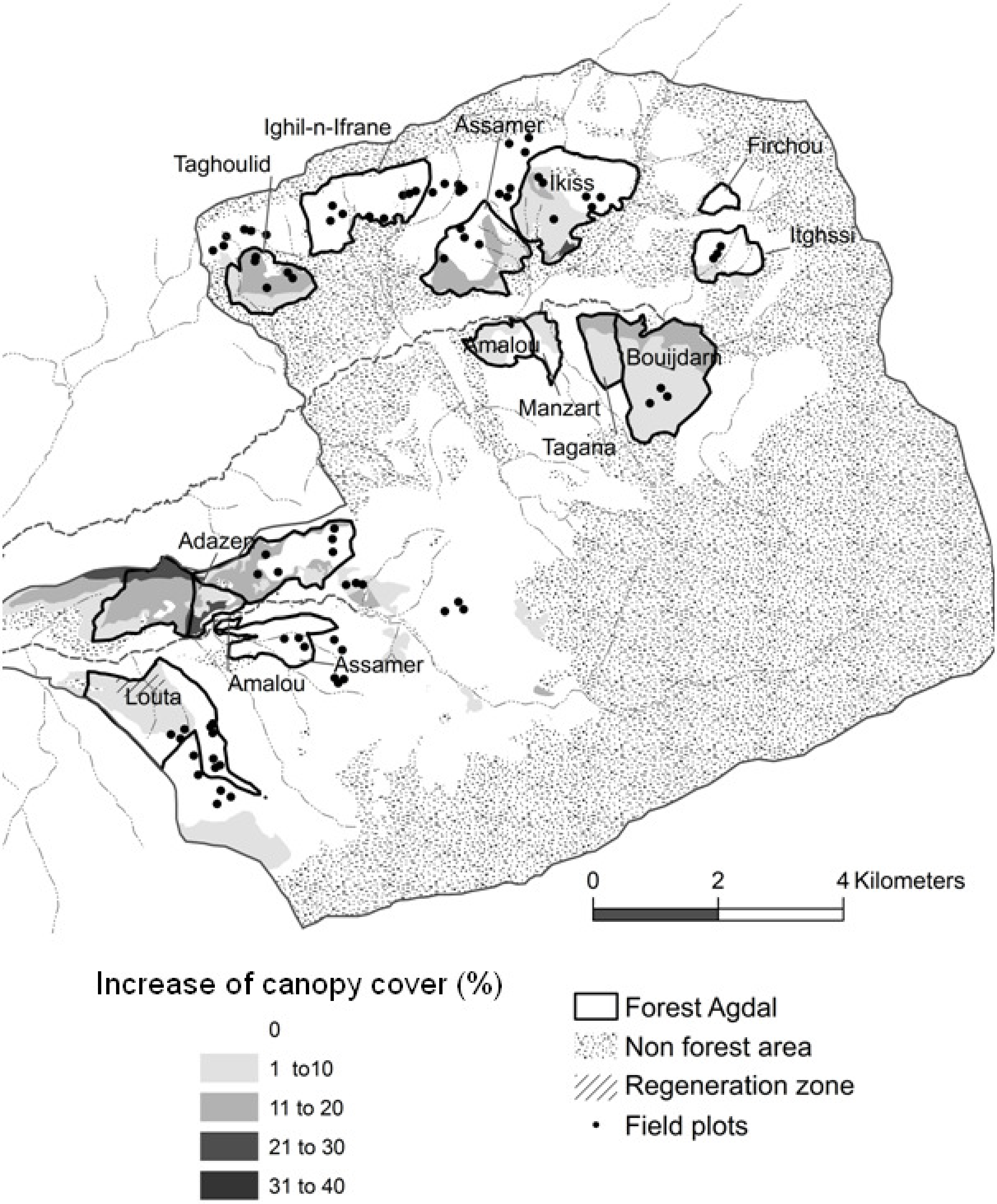

Ighil-n-Ifrane
Assamer
Taghoulid
Firchou
Ikiss
Itghssi
Amalou
Bouijdam
Manzart
Tagana
Adazen
Assamer
Amalou
Louta
0
2
4 Kilometers
Increase of canopy cover (%)
0
1 to10
11 to 20
21 to 30
31 to 40
Forest Agdal
Non forest area
Regeneration zone
Field plots

Fig. 4

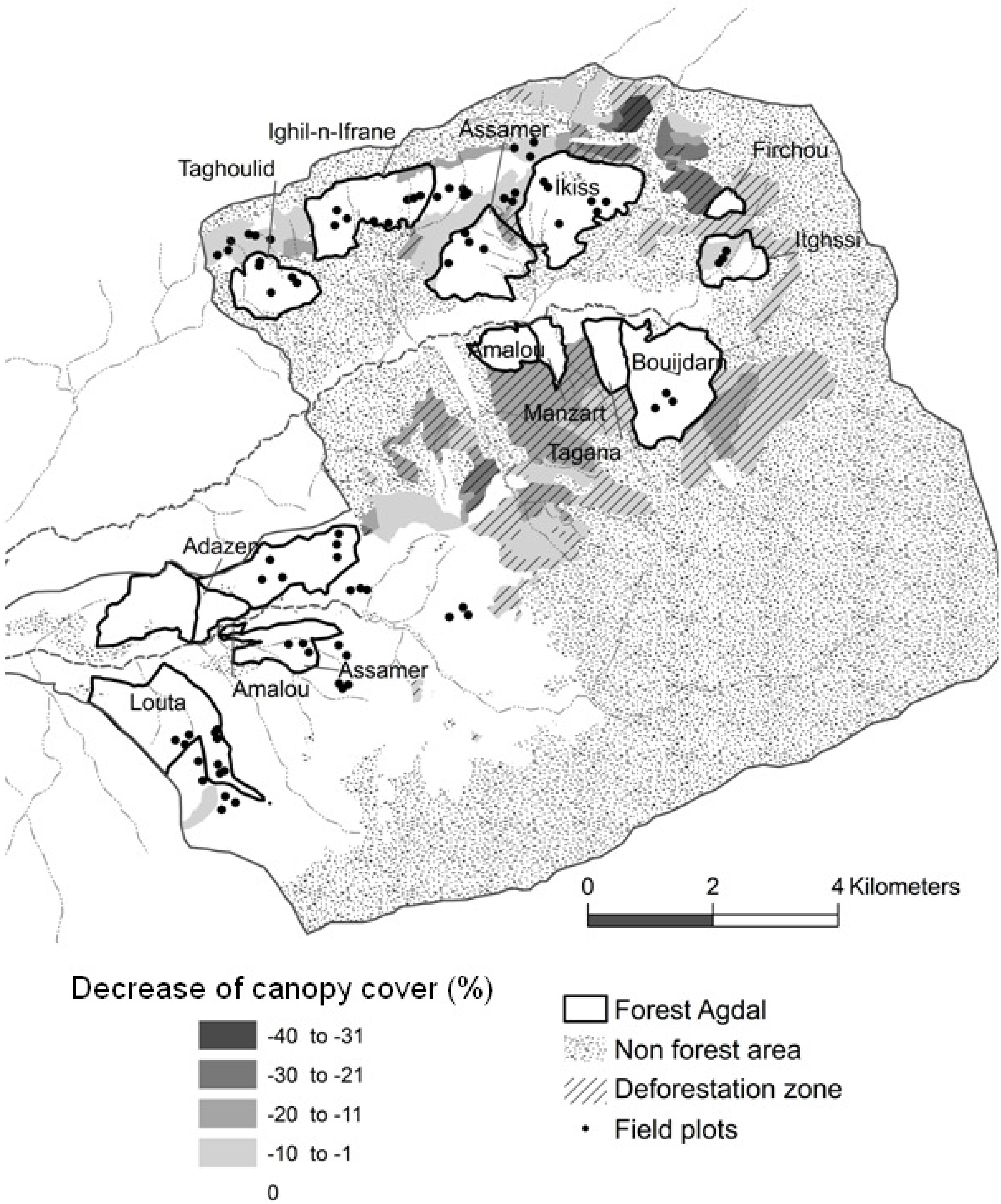

Ighil-n-Ifrane
Assamer
Taghoulid
Firchou
Ikiss
Itghssi
Amalou
Bouijdam
Manzart
Tagana
Adazen
Assamer
Amalou
Louta
0
2
4 Kilometers
Decrease of canopy cover (%)
-40 to -31
-30 to -21
-20 to -11
-10 to -1
0
Forest Agdal
Non forest area
Deforestation zone
Field plots

Fig. 5

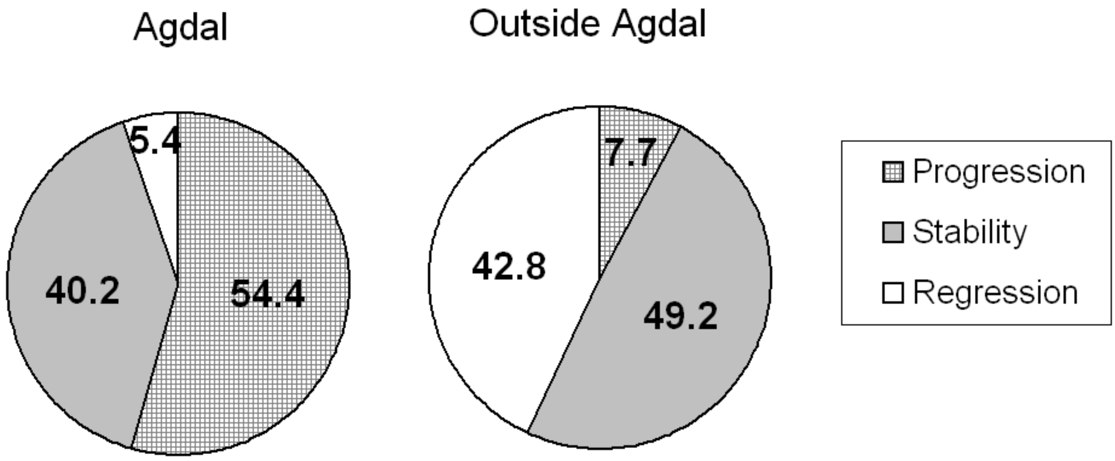

Agdal
Outside Agdal
5.4
40.2
54.4
7.7
42.8
49.2
Progression
Stability
Regression

Fig.6

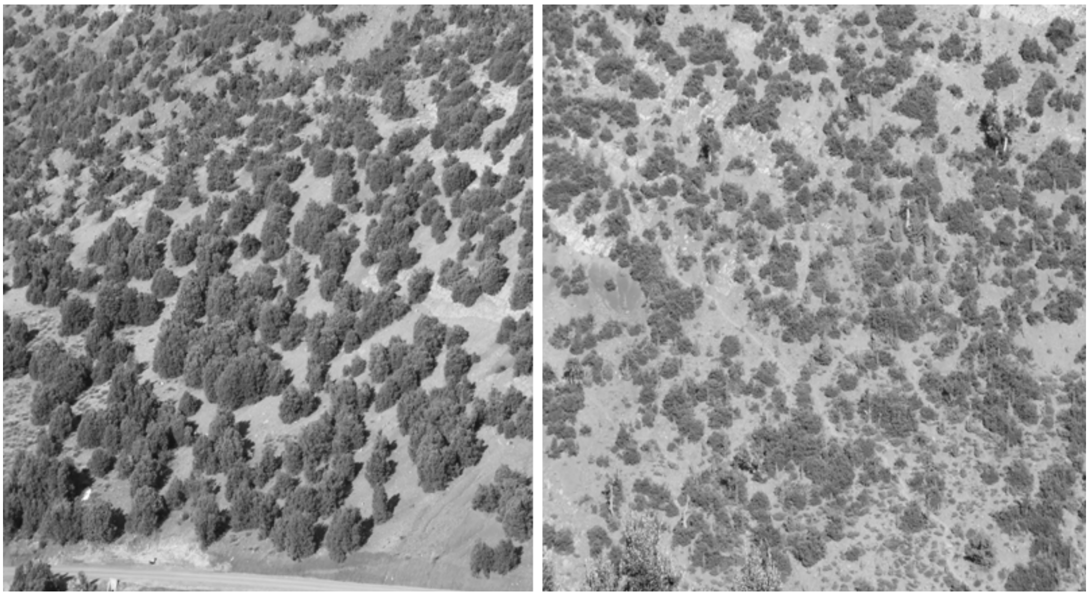


Fig. 1. Location of the Aït Bouguemez Valley, High Atlas, Morocco.

Fig. 2. Comparison of the canopy cover percentages from visual interpretation and from ground observations.

Fig. 3. Positive changes of canopy cover percentage (increase) between 1964 and 2002 in the Aït Bouguemez Valley

Fig. 4. Negative changes of canopy cover percentage (decrease) between 1964 and 2002 in the Aït Bouguemez Valley

Fig. 5. Trend of wood vegetation according to the management modes

Fig. 6. Two stands of holm oak having the same ecological conditions, the left one is managed as *agdal*, the right one is outside *agdal* with cypress plantations.

References

Armitage, D., (2005). Adaptive capacity and community-based natural resource management. Environ. Manag. 35(6): 703-715.

Artz, N.E., Norton, B.E., O'Rourke, J.T., 1986. Management of common grazing lands: Timahdite, Morocco, in: Bostid (Eds.), Proc. Conf.. Common Property Resource Management. National Research Council, Washington, DC, pp. 259-280.

Aubert, P.M., Leroy, M., Auclair, L., 2009. Moroccan forestry policies and local forestry management in the High Atlas : a cross analysis of forestry administration and local institutions. Small-scale For. 8, 175-191.

Auclair, L., Alifriqui, M., 2005. Les *agdals* du Haut Atlas marocain : les enjeux d'une recherche pluridisciplinaire. Cah. Rech, 3. Centre Jacques Berque, Rabat, pp. 60-79.

Auclair, L., 2005. De nouveaux enjeux pour de vieilles pratiques de gestion : les *agdals* forestiers du Haut Atlas central (Maroc), in: Weber, J. (Eds.), Arrangements Institutionnels et Gestion de la Biodiversité. Institut Français de la Biodiversité, Paris, pp. 74-79.

Auclair, L., 1996. L'appropriation communautaire des forêts dans le Haut Atlas marocain. Cah. Sci. Hum. 32, 177-194.

Barbéro, M., Bonin, G., Loisel. R., Quezel.P., 1990. Changes and disturbances of forests ecosystems caused by human activities in the western part of the Mediterranean basin. Vegetatio 87, 151-173.

Becker, C.D., Ghimire, K., 2003. Synergy between traditional ecological knowledge and conservation science supports forest preservation in Ecuador. Conservation Ecology 8(1): 1. [online] URL: http://www.consecol.org/vol8/iss1/art1/

Berkes, F., 1999. Sacred Ecology: Traditional Ecological Knowledge and Resource Management. Taylor & Francis, Philadelphia.

Berkes, F., Colding, J., Folke, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecol. Appl. 10:1251–1262.

Berque, J., 1978. Structures sociales du Haut Atlas. PUF, Paris.

Bertaudière, V., Montès, N., Badri, W., T. Gauquelin, T., 2001. Multicaulis structure of *Juniperus thurifera*: adaptation to a severe environment? CRAS, Série III, Sciences de la vie 324:627-634.

Bourbouze, A., 1982. Déplacements des troupeaux et utilisation des parcours dans le Haut Atlas Central. Prod. pastor. Soc. 10, 34-45.

Bourbouze, A., 1999. Gestion de la mobilité et résistance des organisations pastorales des éleveurs du Haut Atlas marocain face aux transformations du contexte pastoral maghrébin, in: Niamir-Fuller, M., Turner, M.D. (Eds.), Managing mobility in African rangeland: the legitimization of transhumant pastoralism. Immediate technology Publications, London.

Bray, D.B., Ellis, E.A., Armijo-Canto, N., Beck, C.T., 2004. The institutional drivers of sustainable landscapes: a case study of the ’Mayan Zone’ in Quintana Roo, Mexico. Land Use Pol. 21, 333–346.

Carmel, Y., Kadmon, R. 1998. Computerized classification of Mediterranean vegetation using panchromatic aerial photographs. J..Veg. Sci. 9, 445-454.

Cayuela, L., Rey Benayas, J.M., Echeverrı, C., 2006. Clearance and fragmentation of tropical montane forests in the Highlands of Chiapas, Mexico (1975–2000). For. Ecol. Manag. 226, 208-219.

Colchester, M., 1994. Sustaining the forests: The community based approach in South and South-East Asia. Dev. Chang. 25, 69–100.

Cordier, J.B., Genin, D., 2008. Pratiques paysannes d'exploitation des arbres et paysages forestiers du Haut Atlas marocain. Rev. For. Fr. 50, 571-588.

Couvreur, G., 1968. La vie pastorale dans le Haut Atlas Central. Rev. Géog. Maroc 13, 3-47.

Dalle, S.P., De Blois, S., Caballero, J., Johns, T., 2006. Integrating analyses of local land-use regulations, cultural perceptions and land-use/land cover data for assessing the success of community-based conservation. For. Ecol. Manag. 22, 370-383.

Davis, D.K., 2005. Potential forests: degradation narratives, science, and environmental policy in protectorate Morocco, 1912-1956. Environ. Hist. 10, 211-238.

Defourny, P., 1990. Méthode d'évaluation quantitative de la végétation ligneuse en région soudano-sahélienne à partir de données Landsat TM (Burkina Faso), in: Lafrance, P., Dubois, J.M. (Eds), Apports de la télédétection dans la lutte contre la sécheresse. John Libbey Eurotext, Montrouge, pp. 63-74.

Epp, H., Peden, D., Herlocker, D., 1983. The use of large scale aerial photography to determine wood biomass in the arid and semi-arid areas of Kenya, in: Proc. International Symposium of the VII commission of the International Society of photogrammetry and remote Sensing, Toulouse, France, pp. 415-422.

Espelta, J. M., Habrouk, A., Retana, J., 2006. Response to natural and simulated browsing of two Mediterranean oaks with contrasting leaf habit after a wildfire. Ann. For. Sci. 63, 441-447.

Fairhead, J., Leach, M., 1996. Misreading the African landscape: Society and Ecology in the Forest Savanna-Mosaic. Cambrige University Press, Cambridge.

FAO, 1995. Forest resources assessment 1990, Non tropical developing countries. http://www.fao.org/docrep/007/v8050e/v8050e07.htm (accessed 03/05/2010).

Folke, C. 2004. Traditional knowledge in social–ecological systems. Ecol.Soc. 9(3): 7. [online] URL: http://www.ecologyandsociety.org/vol9/iss3/art7/

Fromard, F., Gauquelin, T., 1993. Thuriferous juniper stands in Morocco: Research and conservation for an endangered environment and species. Unasylva, 44, 52-58.

Gauquelin, T., Bertaudière, V., Montès N., Badri, W., Asmode, J.F., 2000. Endangered stands of thuriferous juniper in the western Mediterranean basin: ecological status, conservation and management. Biodivers. Conserv. 8, 1476-1498.

Gautam, A.P., Shivakoti, G.P., Webb, E.L., 2004. Forest cover change, physiography, local economy, and institutions in a mountain watershed in Nepal. Environ. Manag. 33, 48–61

Gautam, A.P., Webb E.L., Eiumnoh A., 2002. GIS assessment of land use/land cover changes associated with community forestry implementation in the Middle Hills of Nepal. Mt. Res. Dev. 22, 63–69

Genin, D., Hervé, D., Rivière, G., 1995. Relation société environnement : la reproduction des systèmes de culture à jachère longue pâturée dans les Andes. Cah. Rech. Dév., 41: 20-30.

Genin, D., Fouilleron, B., Kerautret, L., 2009. Un tempo bien tempéré : Place et rôles des *agdals* dans les systèmes d'élevage du Haut atlas central, in: Auclair, L., Alifriqui, M., (Eds.), *Agdals*: Société et gestion des ressources dans l'Atlas marocain. IRCAM-IRD éditions, Rabat-Marseille, (in press).

Gilles, J., Hammoudi, A., Mahdi, M., 1992. Oukaïmeden, Morocco: A High mountain *agdal*, in: Bromley, D.W., Feeny, D., McKean, M.A., Peters, P., Gilles, J.L., Oakerson, R.J., Runge, C.F., Thomson, J.T., (Eds.): Making the Common work: Theory, Practice, and Policy. Institute for Contemporary Studies Press, San Francisco, pp. 229-246.

Godron, M., Daget, P., Long, G., Sauvage. C., Emberger. L., Le Floch. E., Poissonet. J., Wacquant. J.P, 1983. Code pour le relevé méthodique de la végétation et du milieu. CNRS éditions, Paris.

Hall, F.G., Botkin, D.B., Strebel, D.E., Woods, K.D., Goetz, S.J., 1991. Large-Scale Patterns of Forest Succession as Determined by Remote Sensing. Ecology, 72, 628-640.

Hudak, A.T., Wessman, C.A., 1998. Textural Analysis of Historical Aerial Photography to Characterize Woody Plant Encroachment in South African Savanna. Remote Sens. Environ. 66, 317–330.

Ilahiane, H., 1999. The Berber *agdal* Institution: Indigenous range management in the Atlas Mountainous. Ethnology 38, 21-45.

Ingram, J.C., Dawson, T.P., 2006. Forest Cover, Condition, and Ecology in Human-Impacted Forests, South-Eastern Madagascar. Conserv. and Soc., 4, 194-230.

Jackson, W.J., Tamrakar R. M., Hunt S., Shepherd K. R., 1998. Land-use changes in two Middle Hill districts of Nepal. Mt. Res. Dev. 18, 193–212.

Kadmon, R., Harari-Kremer, R., 1999. Studying Long-Term Vegetation Dynamics Using Digital Processing of Historical Aerial Photographs. Remote Sens. Environ. 68, 164–176.

Kelbessa, M., 2005. The Rehabilitation of Indigenous Environmental Ethics in Africa. Diogenes 52, 17-34.

Ko, D., Bristow, N., Greenwood, D., Weisberg, P., 2009. Canopy Cover Estimation in Semiarid Woodlands: Comparison of Field-Based and Remote Sensing Methods. For. Sci. 55, 132- 141.

Lamb, H. F., Damblon, F., Maxted, R. W., 1991. Human Impact on the Vegetation of the Middle Atlas, Morocco, during the Last 5000 Years. J. Biogeogr. 18, 519-532.

Lecestre-Rollier, B., 1986. L'espace collectif et les conflits chez les Aït Bouguemez (Haut Atlas marocain). Tech. Cult. 7, 95-111.

Lecestre-Rollier, B., 1992. Anthropologie d'un espace montagnard : Les Aït Bouguemez du Haut Atlas marocain. Thèse de doctorat, Université Paris V, France.

Mascia, M.B., Brosius, J.P., Dobson, T.A., Forbes, B.C., Horowitz, L., McKean, M.A., Turner, N.J., 2003. Conservation and the social sciences. Conserv. Biol. 17, 649–650.

Masri, A., 1991. The tradition of hema as a land tenure institution in arid land management: Syria. FAO editions, Rome.

MCEF, 1999. Programme Forestier National, Rapport Final. Ministère Chargé des Eaux et Forêts, Rabat, Maroc.

Michon, G., De Foresta, H., Levang P., Verdeaux, F., 2007. Domestic forests: a new paradigm for integrating local communities' forestry into tropical forest science. Ecology and Society, **12**(2): 1. [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art1/

Montès, N., Gauquelin, T., Badri, W., Bertaudière, V., Zaoui, El H., 2000. A non-destructive method for estimating above-ground forest biomass in threatened woodlands. For. Ecol. Manag. 130, 37-46.

Montès, N., Bertaudière-Montès, V., Badri W., Zaoui, E. H., Gauquelin, T., 2002. Biomass and nutrient content of a semi-arid mountain ecosystem: the *Juniperus thurifera* L. woodland of Azzaden Valley (Morocco). For. Ecol. Manag. 166, 35-43.

Niamir, M., 1990. Traditional woodland management techniques of African pastoralists. Unasylva 160, 49-58.

Nygard, R., Sawadogo, L., Elfving, B., 2004. Wood-fuel yields in short-rotation coppice growth in the north Sudan savanna in Burkina Faso. For. Ecol. Manag. 189, 77–85.

Olsson, E.G.A., Austrheim, G., Grenne, S.N., 2000. Landscape change patterns in mountains, land use and environmental diversity, Mid-Norway 1960–1993. Landsc. Ecol. 15, 155–170.

Pardé, J., Bouchon, J., 1988. Dendrométrie. ENGREF Éditions, Paris.

Plummer, R., FitzGibbon, J., 2004. Co-management of natural resources: a proposed framework. Environ. Manag. 33, 876–885.

RDH50, 2006. Fifty years of Human development and Prospects for 2025. Official Report, www.rdh50.ma (assessed 03/05/2010).

Retana, J., Riba, M., Castell, C., Espelta, J. M., 1992. Regeneration by sprouting of Holm Oak (Quercus ilex) stands exploited by selection thinning. Plant Ecol. 99-100, 355-364 .

Rousset, O., 1999. Dynamique de régénération et interactions positives dans les successions végétales, Installation de *Buxus sempervirens* L. et *Quercus humilis* Miller sur les pelouses des Grands Causses gérées par le pâturage. Thèse de doctorat, Université des Sciences et Techniques du Languedoc, Montpellier, France.

Semwal, R.L., Nautiyal, S., Sen, K.K. Rana, U., Maikhuri, R.K., Rao, K.S., Saxena, K.G., 2004. Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. Agric. Ecosyst. Environ. 102, 81–92.

Spencer, R.D., Hall, R.J., 1988. Canadian large-scale aerial photographic systems (LSP). Photogramm. Eng. Remote Sens. 54, 475-482.

Stevenson, M., 2005. Traditional Knowledge and Sustainable Forest Management. Sustainable Forest Management Network, Edmonton, Alberta. 18 pp.

Taillefumier, F., Piégay, H., 2003. Contemporary land use changes in prealpine Mediterranean mountains: a multivariate GIS-based approach applied to two municipalities in the Southern French Prealps. Catena, 51, 267-293.

Tuominen, S., Pekkarinen, A., 2004. Local radiometric correction of digital aerial photographs for multi source forest inventory. Remote Sens. Environ. 89, 72–82.

Tuominen, S., Pekkarinen, A., 2005. Performance of different spectral and textural aerial photograph features in multi-source forest inventory. Remote Sens. Environ. 94, 256–268.

Uprety L. (2008). Role of institutions and organizations for the sustainable management of forest and pasture as common property resources in Nepal: an overview of the indigenous and traditional practices. Dhaulagiri J. of Sociol. 2, 31-64.

Venema, B., 2002. The vitality of local political institutions in the middle Atlas, Morocco. Ethnology 41, 103-17.

Vermeulen, S.J., 1996. Cutting of trees by local residents in a communal area and an adjacent state forest in Zimbabwe. For. Ecol. Manag. 81, 101–111.

Warren, P.L., Dunford, C., 1986. Sampling semiarid vegetation with large-scale aerial photography. ITC. J. 4, 273-279.

Wimberly, M.C., Ohmann, J.L., 2004. A multi-scale assessment of human and environmental constraints on forest land cover change on the Oregon (USA) coast range. Landsc. Ecol. 19, 631–646.